GEOLOGICAL NOTES ON KOSCIUSKO, WITH SPECIAL REFERENCE TO EVIDENCES OF GLACIAL ACTION.

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(Plates iii.-x.).

I. Introduction.

In the appendix to this paper a list is given of the principal works relating to the above subject as well as to general evidences of glaciation in Cainozoic time in the Southern Hemisphere. Briefly the history of the geographical and geological exploration of Kosciusko is as follows:—

In 1840 Count P. E. de Strzelecki mounted the Alps and called one of the highest peaks Kosciusko, from its fancied resemblance to the patriot's tomb at Cracow (53).

In 1846 Mr. T. S. Townsend, formerly Deputy Surveyor-General in New South Wales, examined the Kosciusko region, and later ran a traverse line along the main dividing line between the waters of the rivers Murray and Snowy (3, p. 227).

During 1851-52 the late Rev. W. B. Clarke geologically examined the Kosciusko region, which he named the "Muniong Range," and for the first time a definite reference is made to evidence there of past glacial action (3).

Mr. Clarke states that "Probably in earlier times glaciers did form; for I saw more than one unmistakable *bloc perché*, a mass resting on upturned edges of strata." Again he states (*op. cit.*, p. 230), "But I am persuaded that formerly true glacier ice was formed on the Muniong, and I have always thought that the effect of it may have produced a kind of *gold moraine* in places, where auriferous veins came into contact with ice."

In 1855 the late Baron Ferdinand von Müller explored the Kosciusko region, chiefly botanically. He speaks of "glaciers" and "ice masses" at Kosciusko, but really refers not to true glacier ice but to snow masses which are characteristic of Kosciusko in winter, and which Mr. Clarke aptly describes thus (*op. cit.* p. 225) :—"The snow itself was not exactly in the condition of that which I saw on the glaciers of Mont Blanc, and which is called "névé," nor was it strictly "neige;" it partook of the characters of both, and though not lying on ice but on the rocks, was certainly in a transition state, being partially consolidated. It had been, I doubt not, often partially thawed and re-congealed, the snows of many winters contributing to it. Hence its imperfect crystalline structure."

In January, 1885, Dr. R. von Lendenfeld made a cursory examination of the Kosciusko Plateau, spending a couple of days near the summit (11, 12). Although he did not actually observe ice-grooved rock surface, nor striated boulders nor moraines, he nevertheless concluded from the general aspect of the surface of the granite above the altitude of 5,800 feet, that the Kosciusko Plateau had at one time been glaciated from its highest points (over 7,000 feet), down to that level.

During 1889 and 1893 one of us (Mr. Richard Helms) visited the Australian Alps and found very definite traces of glaciation in the form of moraines, and exhibited to this Society an ice-scratched block from Kosciusko (6). The conclusion arrived at in a subsequent paper was that the ice which glaciated Kosciusko came down at least as low as 5,200 feet above the sea. It is suggested that the numerous small circular lakes in the Monaro region, not far from the Kosciusko Plateau, and lying at altitudes of only about 3,000 feet, may also be of glacial origin (7).

In 1895 Mr. J. B. Jaquet, A.R.S.M., F.G.S., examined and reported upon a part of the Kosciusko Plateau (9). Mr. Jaquet did not see any definite traces of glacial action in the part of the plateau visited by him, and as a matter of fact in the localities examined by him such traces are not conspicuous.

In 1897 the Rev. J. Milne Curran made a detailed examination of the greater part of the Kosciusko Plateau and embodied the results in a paper to this Society. He concluded that evidences of the former presence of moving glacier ice in the region examined by him were wanting (4, 5).

During the same year Messrs. A. E. Kitson, F.G.S., and W. Thorn examined the Kosciusko Plateau, but not sufficiently far north to come within reach of the principal areas, where the glacial evidences now described in this paper exist (10). They conclude, however, that there are evidences of glacial markings at Mount Etheridge, not far from the summit of Kosciusko (10, p. 369).

During February and March of this year we examined a large portion of the Kosciusko Plateau in company with Mr. F. B. Guthrie, F.C.S., and on these occasions found such clear evidences of ice-action as places the former existence of glacier ice at Kosciusko absolutely beyond dispute.

II. General Geological Features.

The section (Plate vi.) accompanying this paper illustrates our views as to the general geology of the region examined by us. At Cooma a gneissic granite traversed by coarse veins of pegmatite prevails. The folia dip in a general direction of about E. 10° N. at 65°. These gneisses differ materially from the gneissic granite of Kosciusko. The Cooma gneisses are very much crushed and strongly foliated, and, as mentioned, are traversed by veins of pegmatite, whereas the gneissic granite of the Kosciusko Plateau is only slightly foliated, and is devoid of the very coarsely crystalline pegmatites, although containing occasional veins of a hard, fine-grained aplite. The gneisses continue from Cooma towards Jindabyne for about 7½ miles, with smallflows of Tertiary olivine basalt capping it at 5½ miles and 6¼ miles. Beyond 7½ miles the micaceous gneissic rocks give place to sedimentary rocks, apparently part of the series of Lower Silurian radiolarian rocks observed further on towards Jindabyne. At 8½ miles towards Jindabyne there is a strong outcrop of these sedimentary rocks.

At 9 miles granite of the Kosciusko Plateau type first makes its appearance. It has the general aspect of being newer than the gneiss of Cooma. An actual junction, however, between the two was not observed. This granite continues, with occasional cappings of basalt and Tertiary gravels at the points shown on the section to about half a mile beyond Berridale, a total of 21 miles beyond Cooma. At the latter spot there is a sharp junction line between this granite and some black chiastolitic shales and radiolarian cherts. The altitude of this junction line on the main road is about 2,530 feet. The chiastolite slates and shales here dip N. 15° W. at 70°. At 22¾ miles an interesting lake, Lake Coolapatong, is seen about half a mile to left of the road. One of us (Mr. Helms) has suggested that it may be of glacial origin. Its altitude is approximately 2,400 feet.

At Barney's Ridge, from 24 miles to 27 miles, 15 chains from Cooma, there is a great development of radiolarian cherts and shales. As these are striking in the direction of Stockyard Creek, Byadbo, where Mr. J. E. Carne, F.G.S., has discovered, in rocks lithologically identical, numerous Lower Silurian graptolites (47). There can be little doubt, we think, that these rocks too at Barney's ridge are Lower Silurian. This supposition is much strengthened by the recent discovery by Mr. W. S. Dun, Palæontologist to the Geological Survey of New South Wales, of abundant casts of radiolaria in the graptolite shales of Byadbo, similar to the casts in the Barney's Ridge cherts.

The latter, moreover, closely resemble the Lower Silurian graptolitic cherts and shales of Mandurama in New South Wales, in which one of us (Mr. Pittman) has discovered and described Lower Silurian graptolites.

The chalcedonic pseudomorphs after radiolaria in the cherts at Barney's Ridge vary from 0·75 mm. to 0·150 mm. in diameter. By far the greater number are exactly 0·115 mm. in diameter. The casts are all more or less spherical.

It is obvious that the sedimentary rocks at Barney's Ridge form a basin bounded by granite on the east and on the west sides.

From the point previously mentioned, 27 miles and 15 chains on the road from Cooma to Jindabyne, the typical Kosciusko granite replaces the Lower Silurian rocks, and continues, more or less, without interruption to the Kosciusko Plateau.

The Kosciusko Plateau rises abruptly from the valley of the Crackenback River to an altitude of a little over 5,000 feet (about 5,200 feet) at Boggy Plains up to 6,000 feet at Pretty Point (top of Point) and culminates at an altitude of 7,328 feet at the summit of Kosciusko, where Mr. Wragge's Meteorological Observatory now stands.

The plateau is for the most part formed of gneisssic granite very full of dark enclosures. These are mostly not basic segregations or secretions, but fragments torn from older rocks, some of them being fragments of micaceous quartzite and quartz schist. The folia of the granite strike about S.S.W. and N.N.E., dipping chiefly to E.S.E. at varying angles, perhaps 70° being near the average.

The granite is traversed by dykes of pyroxene-amphibolite rocks, passing by decomposition into a chlorite rock. There are also present whitish veins of hard aplitic granite, which seem of somewhat later origin than the mass of the granite. One of these veins is shown in Plate vii

The granite is also traversed by dykes of olivine-basalt containing enclosures of granite. A large dyke of this kind may be observed at Strzelecki's Pass (Lendenfeld), close to Russell's Tarn (Helms), a short distance from Mount Townsend. Another on the main dividing ridge above Garrard Tarn (Harnett's Lake), and a third on the west side of Lake Merewether (Blue Lake). (Plate iii.). A very interesting dyke rock was discovered by us at a point about one-quarter of a mile up Evidence Valley (Valley of Blue Lake) from its junction with the Snowy River. The dyke is about 7 feet wide and strikes E. 5° N., and is vertical. It is almost entirely formed of the minerals nepheline and ægirine. Mr. G. W. Card, A.R.S.M., F.G.S., determined the latter mineral for us. The nepheline is in beautifully developed idiomorphic to hypidiomorphic crystals, showing perfect rectangular or hexagonal outlines in thin sections. Sanidine is present in long delicate acicular crystals, singly twinned. The rock is therefore essentially a phonolite. Sedimentary rocks, as shown on the map (Plate iii.), are represented by slates, phyllites, and felspathic quartzites, which are very possibly of Lower Silurian age. No fossils, however, macroscopic or microscopic were observed in them by us. We would add that the frequency of earthquake shocks in the neighbourhood of Cooma (see appendix, 51) indicates that crustal cracking and orogenic movement is probably still in progress in this region.

III. Evidences of Glacial Action.

These may be grouped as follows :—

1. Smoothing of rock surfaces.
2. *Roches moutonnées.*
3. Grooved and striated rock surfaces and striated boulders.
4. Erratics and perched blocks.
5. Terminal and lateral moraines.
6. Lakes and tarns of glacial origin.

As regards No. 1, Professor Lendenfeld has already noted that the rocks of gneissic granite at the Wilkinson Valley, near Kosciusko, and at "Tom's Flat" (Thompson's Flat), near Pretty Point, are smoothed and hollowed-out in a manner very suggestive of glacier action (11, 12); and one of us (Mr. Helms) has already commented on the fact that from Mount Kosciusko down to the level of Boggy Plains, the granite surface over a large area shows evidence of having been planed down by glacier ice (7).

The recent examination by us of part of the Kosciusko highlands has confirmed these opinions as to the general smoothing of the rock surfaces in the Kosciusko region between altitudes of 7,150 feet and 5,600 feet.

In a paper of an introductory character like the present, it may be convenient to describe these evidences in the order in which a traveller following the usual route from Cooma *viâ* Jindabyne and Boggy Plains to Kosciusko would be likely to see them. We have, however, departed from this rule in the case of localities where the evidence of glaciation is obscure, such areas being treated of last. If, therefore, the evidences at Boggy Plains, Pretty Point, and the flats near Porcupine Ridge and Betts' Camp be passed over for the present, it may be assumed that the observer has reached the right branch of the Snowy River near its source. At the point where the track to Kosciusko from Betts' Camp crosses the right branch of the Snowy River there is a little morainic material in the valley bottom with a few tarns lying higher up.

At about 30 chains N.N.W. of this point, more in the direction of the dray track than of the bridle track, the observer may notice two moraines of rough angular granite blocks trailing down from a spur of the Etheridge Range towards the Snowy River. If this spur be now followed in a south-west direction for half a mile, so as to rejoin the bridle track to Kosciusko, the observer will see a fairly well marked lateral moraine just before the crest of the ridge of the Etheridge Range is reached, at a point $1\frac{1}{4}$ miles E. 33° N. from the Kosciusko Observatory.

The altitude of the upper end of this moraine is about 6,660 feet, which is only a trifle lower than the upper end of the moraine to be described later near Townsend's Pass (Lendenfeld) in the Snowy Valley, these two being the highest moraines observed by us in the Kosciusko region. Further along the bridle track to Kosciusko a number of hummocky rock masses, having all the appearance of *Nunatakr*, form the capping of the Etheridge Range. The altitude at the base of these is about 6,910 feet. The rocks up to the base of the *Nunatakr* show evidence of having been much smoothed; and as grooved rocks were seen by us near Mount Townsend up to a level of at least 6,850 feet, it is only reasonable to conclude that the ice surface near these *Nunatakr* stood at an altitude of at least 6,910 feet. Half a mile further along the bridle track is Ramshead Pass, about one-quarter of a mile E.S.E. from the Kosciusko Observatory. The rocks at this pass, 7,000 high, show evidence of having been smoothed, probably by ice, from the bottom of the pass up to a level of 7,150 feet, this being the extreme upward limit to which possible ice-action was traced by us in the Kosciusko Plateau. From Ramshead Pass (Lendenfeld) a view may be obtained of the first of the glacial lakes, Lake May (or Cootapatamba, or Kosciusko).

Lake May (*Lake Cootapatamba*, *Lake Kosciusko*).—This lake bears S. by E. from the Kosciusko Observatory, and is distant from it about three-quarters of a mile.

An examination of the valley which descends from Ramshead Pass to the lake shows throughout ice-smoothed rock surfaces and moraine material with occasional ice-scratched blocks. The last mentioned are rare, as might have been expected in a locality where the dominant rock is a coarsely crystalline gneissic granite, very unsuited to receiving or retaining glacial markings. Such few boulders as exhibit glacial markings are of felspathic quartzite, and were derived from the east side of the valley.

The lake which is about one-quarter of a mile long and has a maximum depth of about 17 feet, is bounded, at its lower end, by a very well marked terminal moraine. The latter is slightly crescent-shaped with the convex side of the crescent directed down the valley.

From its west extremity the moraine trends E. 10° S. for 6 chains, then E. 8° N. for 6 chains, then N.E. for about 8 chains, passing in this last direction into lateral moraine. The best ice-scratched blocks obtained by us were at the base of the terminal moraine near its east end.

While the length of this terminal moraine does not exceed one-quarter of a mile, its height, at this east end, is a little over 40 feet, and near the centre about 75 feet. The blocks in the moraine are nearly all granite, and are mostly from 3 feet up to about 8 feet in diameter; a great number being of this larger size. Occasionally blocks were observed up to 10 or even 12 feet in diameter.

It was only on the east side of the moraine that fragments of phyllite and quartzite were found. This is accounted for by the fact that these sedimentary rocks form the bed rock only on the eastern side of the valley, as shown by the geological sketch map (Plate iii.). The general strike of these sedimentary rocks is about S. 8° E., and is, therefore, nearly parallel with the trend of the valley.

It is probable that these quartzites are identical with those upon which is situated the striated rock surface near Townsend's Pass, about two miles distant, in a N. by E. direction, and to be described later.

At a total of about 22 chains below the south end of Lake May is a second terminal moraine obviously older than the preceding. Like the latter it is crescent-shaped, being thickest at the middle and slightly looped down the valley (Plate v., fig. 1).

It is about 18 chains in length as terminal moraine proper, and is extended further, in a N.E. direction, as lateral moraine.

The level of the creek where it has cut through this lower terminal moraine, at the lower side of the embankment, is 95 feet below the top of the embankment immediately to the west, and is 180 feet below the level of the western end of this moraine, which is its highest point. As there can be little doubt that the height of the central part of this moraine has been lowered a good deal by denudation, it may fairly be assumed that at its centre it was formerly, perhaps, at least from 20 to 30 feet higher than at present, which would make its thickness from 100 feet up to about 120 feet. If, however, this moraine was originally as high at the centre as at the sides, its height at the centre would have been originally 180 feet.

As regards the development of the glacier ice in this valley it is evident from the duplication of the terminal moraine embankments and from the space which separates them, that there have been two distinct epochs or phases there of glaciation, the older glacier being about one quarter of a mile longer than the newer and having a larger terminal moraine.

There must have been a long pause of the glacier snout at the present position of the lower moraine.

Subsequently the glacier retreated more or less rapidly up the valley until its front rested upon the present site of Lake May. There was then a second long pause during which the second terminal moraine embankment, about one-quarter of a mile long and 75 feet in greatest thickness, was slowly built up. Then came a second retreat of the glacier up the valley, perhaps more gradual than the first, and the ice melted back to near Ramshead Pass without leaving any further definite terminal moraine embankment, although its retreat is marked by deposition of a certain amount of irregularly distributed moraine matter along the bottom of the valley, with a little lateral moraine along its eastern side.

As regards the thickness of the ice during the later of these two glaciations, an examination of the smoothed granite surfaces on the west side of this valley shows that the valley must have been glaciated up to a level of at least 150 feet above the present level of Lake May, and as the moraine dam at this lake is about 75 feet high, a further thickness of perhaps that amount might be added for the former depth of the glacier ice at this epoch. The ice, therefore, in this valley was probably at this time at least 200 feet in thickness.

During the earlier phase of this valley glaciation, when the lower terminal moraine was formed, as the moraine is now 95 feet high and was formerly at least 120 feet high, possibly 180 feet, the ice at this terminal moraine must at one time have been probably from 150 to 200 feet thick, and higher up the valley cannot have been much less than 300 feet thick. A cursory examination of the rocks for a short distance below the level of this older terminal moraine showed that they were more or less smoothed, apparently by ice, for some distance down the valley. Definite evidence, however, of ice action was not observed below the lower moraine dam, but it would be premature, in the absence of detailed examination, to conclude that no glacial evidences exist at a lower altitude.

The Wilkinson Valley.—The highest part of this valley, just beneath Mount Townsend, was not examined by us, and the following remarks apply only to the portion of it which lies within a distance of about a mile below the above limit.

Evidences of glacial action are not so fresh or distinct there as in other localities, about to be described, at Kosciusko. Neither grooved nor ice-scratched rocks were observed, but the granite surface was seen to be smoothed and hollowed-out in a manner which cannot well be explained except by ice-action, as Professor Lendenfeld has already argued (12, p. 47). In the small valley, the head of which is separated by a very low divide from the Wilkinson Valley, and which lies immediately below and due west of the Kosciusko Observatory, several low moraine banks were noticed by us. The two principal ones bear about 315° and 333° respectively from the Kosciusko Observatory. They are not more than from 10 to at least 15 feet in height.

The Snowy Valley (*left branch*).—As already mentioned, near Ramshead Pass, which divides the head of the Snowy River from the Lake May Valley, the granite shows evidence of ice-wear up to a level of about 7,150 feet, that is up to about 150 feet above the level of Ramshead Pass. If a descent be made into the head of the Snowy Valley from this pass, it will be seen that a large amount of moraine material extends for several hundred feet above the valley bottom. This is deposited chiefly on the west side of the valley. Smoothed surfaces of quartzites were observed at three places between the head of the valley and the small recent landslip, $1\frac{1}{4}$ miles northerly from Ramshead Pass. Beyond this point the valley bends sharply to the east, but if the observer continues on a northerly course for a little over one-quarter of a mile further so as to cross the Snowy and ascend towards "Townsend's Pass," to the south of Lake Albina, he comes upon a beautifully preserved remnant of a lateral moraine, already alluded to by one of us (Mr. Helms, 7, p. 358). (See Plate x., fig. 2).

This moraine trends in a S.E. direction from Townsend's Pass towards the Snowy River. It bears about N. 15° E. from

Kosciusko Observatory, and is a mile and a half distant. It forms a conspicuous feature in the landscape, bearing a striking resemblance to a railway embankment. Its trend is E.S.E. and W.S.W., its upper end lying in the latter direction. It is nearly a third of a mile in length, the exact measurement being about 32 chains.

Beyond this limit, however, it has been considerably denuded, and for a further distance of over one-quarter of a mile it is represented merely by irregular hummocks of more or less redistributed moraine material. Its summit is flat, from 20 to 30 yards wide, and has a slope to the E.S.E. of 1 in $4\frac{1}{2}$ for the first 100 yards, and 1 in 5 for the remainder of the distance.

The moraine is composed chiefly of angular and subangular blocks of granite and slate with a certain amount of interstitial sandy material.

The fragments of granite are usually from 3 inches to 1 foot in diameter and are mostly subangular or rounded. Blocks up to 2 feet in diameter are not infrequent. Three angular granite erratics were observed by us in this moraine, respectively measuring $6\frac{1}{2}$ ft. × 5 ft. × $4\frac{1}{4}$ ft., 12 ft. × 4 ft. × 3 ft., and 14 ft. × 8 ft. × $5\frac{1}{2}$ ft. As a rule the granite boulders show neither grooves nor striæ, the coarsely crystalline character of the rock and its easy weathering being unfavourable to the forming or preserving of such glacial markings. A block, however, now exhibited, of fine-grained aplitic granite (which we dug *in situ* out of the moraine) has distinct glacial grooves on its under surface.

The fragments of slate (phyllite) in the moraine vary from 2 inches up to 6 inches and rarely 1 foot in diameter. They are mostly subangular, and out of some hundreds of specimens examined the majority exhibit irregular glacial cuts, grooves, and coarse scratches. The material of this micaceous phyllite is wholly unsuited to receive or retain fine striæ. The upper surfaces of the slate fragments in this moraine seldom, if ever, exhibit either scratches or grooves, all traces of such having been effaced through weathering.

That the whole moraine, as well as the rock surface to the N.E. on which it originally reposed, has undergone an appreciable amount of erosion, since the disappearance of the last of the glaciers is proved by the evidence shown in Plate iv.

Careful measurements convinced us that not less than 9 feet (measured vertically) of moraine and 10 feet of phyllite have been eroded since the retreat of the ice, and this has led to the formation of the small gully which bounds this lateral moraine on the N.E. A total lowering of the surface, therefore, to the extent of at least 19 feet has taken place since the disappearance of the last of the ice. The evidence afforded by the erosion of this small gully, at the side of the lateral moraine, was about the best we were able to obtain as to the approximate date of the latest glaciation at Kosciusko. It is, of course, impossible to estimate the exact time-value of this erosion, but in this respect we would quote the statistics recently obtained by Mr. C. C. Brittlebank, F.G.S., for the rate of erosion of the Myrniong Creek Valley, in Victoria.*

Mr. Brittlebank summarises (*op. cit.* p. 321) the results of his observations as follows :—

Rate of erosion in Werribee River and tributary creeks, Victoria.

Basalt	... 0·02 inches in 5 years	= 1 inch in 250 years.				
Silurian (Slates—T.W.E.D.)	... 0·03	,,	,,	= 1	,,	$166\frac{2}{3}$,,
Granite	... 0·04	,,	,,	= 1	,,	125 ,,
Glacial (Compact Permo-Carboniferous mudstone with small glacial boulders—T.W.E.D.)	... 0·05	,,	,,	= 1	,,	100 ,,

The moraine at Townsend's Pass, Kosciusko, would no doubt have been eroded much more rapidly than any of the rocks studied by Mr. Brittlebank, and the time needed for its erosion

* Austr. Association Adv. of Science, Melbourne, Jan. 1901. "The rate of erosion of some river valleys." By C. C. Brittlebank. Geol. Mag. No. 433. New Series, Dec. iv. Vol. vii. July, 1900, pp. 320-322.

would be relatively so small as to be negligible; and it has accordingly been omitted from the following calculations. As regards the phyllites in view of their highly cleaved and jointed character and their soft micaceous nature, it is probable that erosion, in their case, too, may have progressed at least as rapidly as in the case of the Permo-Carboniferous glacial beds studied by Mr. Brittlebank, and if further allowance be made for exposure to frosts on Kosciusko, and for the great range of temperature to which the rocks there are exposed, it may reasonably be assumed that the erosion at Kosciusko was more rapid than at the Werribee River. At the same time the fact must not be lost sight of that for about six months in the year the moraine at Townsend's Pass is under snow, during which time erosion and weathering would be at a minimum.

Even if the phyllites at the above moraine were eroded at the same rate as the Permo-Carboniferous beds of the Werribee River, that is at the rate of 1 inch in 100 years, at least 10 feet of phyllite having been eroded since the latest glaciation, this would obviously need for its accomplishment $10 \times 12 \times 100$ years $= 12{,}000$ years. For reasons, however, stated above it is probable that these figures are too high. This supposition is confirmed by the freshness and good state of preservation of the glaciated surfaces of granite even in highly exposed positions in the Kosciusko Plateau, not more than one-sixteenth of an inch to 1 inch having been removed by weathering. The original glaciated surface, however, is rarely preserved, except where it has been protected by a covering of moraine.

If the gully to the N.E. of the lateral moraine be followed down from the end of the moraine embankment towards the Snowy River, a small striated rock surface may be noticed of hard slate, and about a couple of yards square, about three chains below the base of the moraine embankment; and at a point still further down towards the Snowy River $7\frac{1}{2}$ chains below the foot of the moraine, and a few feet above the bed of the creek, is another small striated rock surface. The rock in this case is a hard quartzite. It is a few feet above the east bank of the creek, and the magnetic bearing from it to the Kosciusko Observatory is 200° 20′.

The surface measures about 8 feet long by 2 feet wide at the centre, and 1 foot wide at either end. It trends S. 5° E. and N. 5° W., and its surface dips S. 10° W. at 10°. The whole surface has been ground smooth, and is faintly striated. A portion of this is now exhibited.

The striæ run N. 30° W., and S. 30° E., the strike side being on the N.W., as might have been expected, as the valley here falls from the N.W. towards the S.E.

At a point nearly one-quarter of a mile south-east of the preceding is another striated rock surface of quartzite, of the nature of a small *roche moutonnée.* The striæ run from N.W. to S.E.

The altitude of this is about 6,340 feet, whereas that of the previous glaciated surface of quartzite is about 6,400 feet. The level of the summit of the lateral moraine at its lower end is 6,510 feet, while that of the extreme upper end is 6,720 feet. The Snowy Valley below the 6,340 feet *roche moutonnée* was not examined by us in detail, excepting between a point due west of Charlotte's Pass, at the junction of Club Lake (Harnett's Lake, or Garrard Tarn), and the junction lower down of Evidence Valley Creek with the Snowy River. Near the junction of Club Lake Creek with the Snowy River there is a well-marked terrace of what appears to be redistributed moraine material on the right bank of the Snowy River; and several ice-scratched boulders were picked up by us on the left bank of the Snowy, just above its junction with Evidence Valley Creek, the latter having its source in Lake Merewether (the Blue Lake).

About 5,520 feet is the altitude by aneroid of the lowest spot were such ice-scratched pebbles were found by us. This is the lowest level at which any ice-scratched pebbles were observed. It is of course possible that these were not *in situ*, but had drifted down from higher levels. At the same time the gneissic granite along this part of the Snowy Valley shows almost certain evidence of ice-wear, down to at least as far as the junction with Evidence Valley Creek. The distance to this point from Townsend's Pass is about $4\frac{1}{2}$ miles, and we think it may safely be inferred that the Snowy Valley was at one time filled with ice to at least as far down as this.

Before considering the possible thickness of ice in this valley it will be advisable to describe the important collateral evidence in the Lake Albina Valley.

Lake Albina Valley.—The finest glaciated rock surfaces hitherto observed by us are in the Lake Albina Valley.

The upper end of the valley, where the evidences of past glacial action are pronounced, is only about three-quarters of a mile in length, the slope of the bottom of the valley being gradual for this distance, but below the north end of Lake Albina plunging steeply down towards the Murray River. Traced to its commencement the valley is found to begin on the north side of Townsend's Pass (the pass over the main Dividing Range between the Murray and the Snowy River watersheds, due south of Lake Albina). The altitude (by aneroid) of this pass is 6,650 feet.

From the base of the northern slope of this pass to the northern end of Lake Albina the bottom of the valley is filled with hummocky masses of moraine material, surmounted by large granite erratics up to 20 feet in diameter, and it appeared to us to contain more morainic material than any other of the valleys examined by us on the Kosciusko Plateau, with the exception, perhaps, of the Evidence Valley.

The moraine drift has been carried beyond the north end of Lake Albina, and to some height up the eastern slope of the valley, numerous large erratics of granite having there invaded the area of the slate (phyllite) formation. These can be seen in the distance in a photograph by one of us (Mr. E. F. Pittman). (Plate x., fig. 8).

Several small tarns are situated near the upper end of the moraine débris, south of Lake Albina. Lake Albina itself owes its origin to a moraine dam. This has been cut through by the creek, and huge boulders derived from it now fill the bed of the water course at lower levels, the creek north of this moraine plunging down rapidly towards the Murray River. The lake is a little under one-quarter of a mile in length by from about 3 to 5 chains in width. It appears to be fairly deep in places in proportion to its size. Its surface, as measured by aneroid, is about 6,340 feet above the sea. The moraine stuff in the neighbourhood of the lake has been much redistributed, and is partly masked by a covering of recently slipped slate-rubble along its eastern shore. Under these circumstances ice-scratched blocks would not be expected to occur, except very sparingly, and as a matter of fact none were observed by us. The moraine material hides the granite surface from view for the most part up to a level of about 150 to 200 feet above the Lake, but from this level up to the very summit of the ridge connecting Mount Townsend with the main Dividing Range, the steep, and in places almost precipitous, granite surface shows abundant and beautiful evidence of having been intensely glaciated. Projecting corners are rasped off, and more or less deeply grooved. Even sheltered recesses have not escaped the abrading action of the ice, and the grooves and striæ are so fresh on some of them as to appear to be of quite recent origin. Seven more or less extensive grooved surfaces were observed by one of us in an hour's examination of this western side of the valley. The positions of these are shown on the plan, and their altitudes range from 6,530 feet up to 6,820 feet. The last level is within 30 feet of the top of the ridge, separating the Lake Albina Valley from the Wilkinson Valley.

It is quite evident from the way in which the rocks have been ground down on the summit of the ridge that ice of considerable thickness must at one time have passed over it.

The finest grooved pavement observed by us is situated at a point bearing due west of the south end of Lake Albina, and 15 chains distant.

There is a smaller grooved pavement about 10 feet below the larger pavement. The larger one measures about 28 yards from N. to S., and about 25 yards from E. to W. The surface has been ground down to a nearly uniform level, is nearly horizontal and is deeply grooved, the grooves running in perfectly straight lines across the platform in a direction E. 15° N. They are nearly at right angles to the gneissic structure of the granite, and many of them are at least 50 feet in length, and are cut to a depth of one-half to one inch. These grooves form the most incontrovertible evidence as to the grinding action of moving glacier ice. If the observer sights along these grooves in a direction E. 15° N. he will see that they point direct to the large polished *roche moutonnée* on the west shore of Lake Albina, near its southern end, at the point where the lake is so contracted as to be almost divided into two. This beautiful grooved pavement had to be photographed by one of us under rather disadvantageous circumstances, as the sun was shining straight down the grooves, so that they cast scarcely any shadow. The photograph nevertheless gives a fair idea of what part of the pavement is like (Plate x., fig. 1); the pavement must, however, be seen in order to be properly appreciated. The surface is slightly weathered, just sufficiently so to remove the striæ, while the deep grooves, and even some of the shallower, are retained. One very large groove was observed to trend E. 33° N., thus making an angle of about 16° with the general trend of the grooves on the west side of Lake Albina Valley, viz., E. 17° N.

Some of the larger grooves every here and there showed traces of having been slightly pitted as though the block of rock, which acted as the graving tool, had dug in more deeply at such points, joggling as a chisel sometimes does in planing iron.

Nowhere, in the part of the Kosciusko Plateau visited by us, was the intenseness of the glaciation more apparent than in this Lake Albina Valley, it being obvious that the ice not only furrowed out the bottom of the valley, but that it moved in thick, heavy masses over the top of the high ridge separating the Lake Albina Valley from the Wilkinson Valley. The minimum thickness of the ice in the Lake Albina Valley may be estimated from the difference in level between Lake Albina and the top of the glaciated ridge to the west of it, Lake Albina being about 6,340 feet above the sea, and the top of the ridge 6,850 feet; the ice in this valley must have attained a thickness of at least 500 feet. As, however, the top of the ridge itself has evidently been heavily glaciated, this implies that the ice on top of this ridge must have been probably not much less than 100 feet in thickness.

If this were so, as seems most probable, the ice would have been 600 feet thick in the Lake Albina Valley, and its surface close upon 6,950 feet above the sea. As already mentioned the bases of the *Nunatakr* of the Etheridge Range are about 6,908 feet high. Now interesting conclusions necessarily follow from this. As Townsend's Pass is only 6,650 feet high, part of the Snowy Valley glacier may have come over the top of Townsend's Pass, the ice at the Pass being perhaps at one time 200 feet or even 300 feet thick. Similarly at Adams' Pass (between the Snowy Valley and the Wilkinson Valley), the level of which is only about 6,587 feet, the ice must have escaped from the Snowy Valley ice sheet into the Wilkinson Valley below in masses which, at Adams' Pass, were probably at least 250 feet, perhaps 350 feet or more in thickness.

An interesting problem now suggests itself in connection with the glaciation of this ridge between the head of the Wilkinson Valley and Lake Albina, viz.: in what direction did the ice move which so powerfully glaciated the western granite slopes of the Lake Albina Valley up to the top of the ridge? The mean trend of the grooves on the seven glaciated surfaces specially observed is E. 17° N. and W. 17° S. Now did the ice move from the east end or from the west end? If from the west, it must probably have been supplied by the overflow from the Mt. Townsend glacier, which may have overpowered the western part of the ice coming over Townsend's Pass from the Snowy Valley glacier. If it moved from the east, it probably was derived from the Snowy Valley glacier, extended via Townsend's Pass into the Lake Albina Valley, and overflowing the dividing ridge between Lake Albina and the Wilkinson Valley, so as to reinforce the Wilkinson Valley glacier. The carry of the material in the moraine of the Lake Albina Valley suggests a westerly movement of the ice, as while the junction line between the granite and slate nearly coincides with the trend of the Lake Albina Valley (N. & S.), the area west of this line being granite, and that to the east slate, the granite erratics have invaded the slate area, but no slate erratics were noticed as having trespassed into the granite area.

Here, however, the fact must be remembered that the carry of moraine material, especially superficial moraine, as distinct from ground moraine, usually indicates the direction of ice movement during *later* phases of glaciation when the ice, of perhaps, originally, a *mer de glace*, has through reduction in volume been split up into a number of small glaciers, the direction of movement of which has had to conform to the trend of the valleys, whereas the ice of the *mer de glace*, of the earlier phase of glaciation, may have radiated out from its centre of movement more or less independent of the physical features of the underlying rock surface. Judged by the phenomena of "strike-side" and "lee-side" alone, it appeared to one of us (Professor David) that the ice which produced the grooved pavements in the Lake Albina Valley probably moved from the east towards the west. Further observation, however, will be necessary before this interesting question can be settled.

We are now also in a better position to estimate the maximum thickness of the ice in the Snowy Valley, at the time when the ridge from Mount Townsend, west of Lake Albina, was being glaciated.

If the surface level of the ice at Ramshead Pass was not less than perhaps 7,150 feet, as seems probable, it would have been possible for it to have had a fall of 250 feet to the top of the ridge west of Lake Albina, even if it be assumed that the ice on that ridge was at least 50 feet thick. This would give a fall (the distance being two miles) of in round numbers 1 in 42, that is an angle of inclination for the surface of the glacier of $1\frac{1}{2}°$. It is doubtful, however, whether ice will flow at such a low angle of slope as $1\frac{1}{2}°$, 3° being usually about the minimum angle of surface slope observed in moving ice.*

* The Great Ice Age.

If, therefore, the glaciation of this ridge was the work of the Snowy River glacier or ice sheet, the surface of the sheet, if its inclination was 3°, must have been probably at its starting point, if situated close to Kosciusko Observatory, as high as 7,450 feet, that is, as the level of the Observatory is 7,328 feet, over 100 feet above the level of the Observatory, probably a far-fetched hypothesis.

The culminating point, however, of the ice sheet on the Kosciusko Plateau, during the maximum glaciation, need not necessarily have coincided with the present highest point of the land, and may have lain at some point between the Observatory and Lake Albina. In this case the ice in the Snowy Valley may have been about 650 feet to 700 feet or more in thickness opposite Townsend's Pass.

If, on the other hand, the ridge near Lake Albina was glaciated by ice coming from the direction of Mount Townsend, such ice at a fall of 3° would barely have overflowed Townsend's Pass, the level of which is 6,650 feet, the distance from the glaciated ridge being half a mile, and its level 6,850 feet. The distance from Mount Townsend to the glaciated ridge is about half a mile, the level of Mount Townsend 7,260 and that of the ridge 6,850 feet. At a fall of 3°, that is 278 feet per mile and consequently 140 feet per half-mile, on the assumption that the ice was 50 feet thick on top of the glaciated ridge, this would bring the top of the ice below Mount Townsend to a level of 7,040 feet, which is a by no means improbable height for it to have attained.

In this case, which seems the less hypothetical of the two assumptions, the ice in the Snowy River Valley need not have been thicker than about the difference in level between Townsend's Pass and the bottom of the Snowy Valley opposite to it, viz. 300 feet. Whichever hypothesis be adopted, the thickness of ice in the Lake Albina Valley during the glaciation of the ridge west of Lake Albina would be the same, viz., about 500 feet. This agrees closely with the thickness of the ice in the Lake

Merewether (Blue Lake) Valley during the maximum development of the local glacier, as will appear presently.

Lake Merewether (Blue Lake) and Evidence Valley (Helms), to below Hedley Tarn.—Splendid evidences of past glacial action, including the largest and most complete moraine as yet observed in this region, are to be seen at the above locality.

If the area be approached from the west, from the direction of the main Dividing Range, moraine material with ice-scratched fragments of slate (phyllite) may be seen at an elevation of about 6,530 feet at a point about 20 chains W. of the S. W. end of Lake Merewether. Up to this same level also the granite rocks show evidence of having been planed down by ice-action; and a few feet lower, at about 6,500 feet, they exhibit distinct glacial grooves.

Further east, at 12 to 15 chains west of Lake Merewether, the surface of the gneissic granite is most wonderfully grooved and dressed in a manner which could only have been accomplished by a thick mass of moving glacier ice (see Plate vii.).

The level of this rocky promontory at the spot photographed is about 6,260 feet.

It affords a fine and impressive piece of evidence as to the former presence of moving glacier ice.

Though the granite surface has been somewhat weathered since the glaciation, so that all striæ have disappeared, the grooves remain, and in many cases are in a very good state of preservation. For every foot in width of granite surface, measured at right angles to the trend of the grooves, there are from 4 to 5 grooves. The grooves are from 1 inch up to 6 inches in width, and from $\frac{1}{4}$ inch up to about $1\frac{1}{2}$ inches in depth. At the spot mentioned above they run in a direction of 140° (that is S. 40° E., is the lee side) and preserve an almost absolutely straight course irrespective of the ups and downs of the granite surface, their trend being straight towards the large moraine which bounds Lake Merewether (the Blue Lake) on the south. Even small vertical faces of granite, opposed to the path of the ice, are deeply grooved. The grooves cross the planes of foliation in the granite at a wide angle, as the latter trend N.N.E. and S.S.W., whereas the grooves run nearly N.W. and S.E.

In Plate vii., the white vein of euritic granite is parallel to the planes of foliation, and the plate shows that obviously the grooves in the granite make a wide angle with the foliation planes. If the gully be followed down to the edge of Lake Merewether the grooves may still be traced on the sloping surface of granite close to the lake shore, and it is obvious that they dip below the surface of the water, the level of which is about 6,150 feet.

In every case it is obvious that, in this vicinity, the N.W. is the strike side, and the S.E. the lee side.

If now a northerly course be followed towards the head of the main valley, it will be noticed that the valley very nearly follows the junction line between the slate and granite (see map, Plate iii.). Slate erratics are found in places resting on glaciated surfaces of granite. One of these measured 5 feet × 3 feet × 4 feet, and in several cases typical perched blocks may be seen, one of which is shown in the photograph exhibited, taken by one of us (Mr. Pittman).

At a quarter of a mile above the Blue Lake, a small terminal moraine crosses the valley, slightly breached by the creek at its west end. It is about 10 chains long and trends in a W.S.W. and E.N.E. direction, and is of no great height. It obviously forms one of the last embankments left by the glacier as it retreated to the head of the valley. Its level is about 6430 feet.

At about a quarter of a mile still higher up the valley on its eastern side, and about 12 feet above the level of the creek, is a small surface of quartzite, ground smooth and striated in two directions, viz., N. 12° W. and S. 12° E. and W.N.W. and E.S.E.

If, now, we return to Lake Merewether, it will be noticed that the water flowing out of it escapes through a breach in the terminal moraine, at a level of about 6,150 feet. The terminal moraine extends from the outlet of the lake in a direction about S. 35° W. for about 15 chains, and for about 10 chains in a direction N. 10° E. from the east side of the outlet. The top of the moraine rises to a level of 6340 feet, about 160 feet above the surface of Lake Merewether. The exact depth of the lake is not known, but it is thought by local residents to be not less than 40 feet in its deepest part, in which case the terminal moraine is probably about 200 feet in height.

It is difficult, however, to draw the line (if any exists) between this terminal moraine and the remarkable moraine now to be described. If the spur to the west of the outlet of Lake Merewether be ascended further to the west, it is found to lead up to one of the most interesting glacial features in the whole Kosciusko region, a wonderfully perfect moraine, even more like a huge railway embankment than the smaller one already described near Townsend's Pass. This remarkable feature has already been referred to by one of us (Mr. Helms) in an earlier paper (7, pp. 357-358).

This moraine is about 29 chains in length, measured along the top of the ridge, its width at the top being uniformly about 16 yards. Its trend from its western end, where it abuts against the junction line between the slate and granite, is first E. 5° S. for 15 chains, then E. 7° S. for 14 chains. It is bounded on either side by steep slopes, its summit is nearly level, and its altitude is about 6,550 feet, that is just 400 feet above the level of the surface of Lake Merewether. The whole amount, however, of the material between these levels is not moraine, as to the S.W. of Lake Merewether the grooved granite surfaces can be traced up to a level of 6,280 feet, where they disappear under the moraine. The remainder, therefore, of the slope between 6,280 feet and 6,550 feet, in all a thickness of 270 feet, may be looked upon as moraine, so far as the northern slope of the moraine is concerned.

As regards the southern slope, grooved surfaces of granite outcrop the levels up to 6,330 feet, so that on this side the moraine material may not be more than 220 feet in thickness. The number of beautifully glaciated boulders in this moraine is remarkable. A cart-load of such boulders could be collected from the moraine by a couple of men in half an hour. The blocks of rock in the moraine are mostly of granite, but slate and quartzite fragments are numerous. The last-mentioned, of course, retain the striæ best. Two of these are now exhibited. (See Plates viii.-ix.).

The blocks are mostly from about 9 inches up to 1½ feet in diameter, occasionally as much as 5 feet. All the fragments of quartzite and slate examined showed glacial markings.

If this moraine be viewed from a distance of three-quarters of a mile to the S.W., it will be seen that it is apparently confluent with the closely crowded group of terminal moraines immediately below Hedley Tarn. It was not clear to us as to whether it should be regarded as a lateral, median or terminal moraine. The grooves on the glaciated granite surface immediately N. of the moraine trend, as already stated from N. 40° W. towards S. 40° E., whereas the general trend of the moraine is W. 6° N. and E. 6° S., so that the ice which glaciated the granite beneath the moraine appears to have moved at an angle of about 45° to the general trend of the moraine. More observation is needed for the correct interpretation of the mode of origin of this remarkable and beautifully preserved moraine.

About one-quarter of a mile below the outlet to Lake Merewether, the grooves on some of the large blocks of granite in the ground moraine trend S. 35° E., and at a point a little further down the valley, and about 300 yards above the upper end of Hedley Tarn, and a few chains to the S.W. of the creek flowing from Lake Merewether to Hedley Tarn, the surface of the granite, where it emerges from beneath the morainic material, shows abundant evidence of having been powerfully ground down and grooved by moving glacier ice. The grooves may be traced right up the shoulder of the ridge to the west of Hedley Tarn to an altitude of about 6,380 feet, whereas the level of Hedley Tarn is about 6,110 feet. This shows that the glacier ice was at least as thick as the difference in level between these points, viz., 270 feet.

As, however, the rocks are deeply grooved up to 270 feet above Hedley Tarn, allowance must be made for a further thickness of glacier ice sufficient to supply the necessary pressure for the grooving at the highest levels. Some idea of what this thickness was may be formed from the height of the adjacent E. and W. moraine previously described, its altitude being 6,550 feet, that is 480 feet above Hedley Tarn. It may therefore safely be assumed that the ice was at least 400 feet, perhaps 500 feet thick, at the time when the glacier extended from Mount Twynam to Hedley Tarn, a distance of one and one-half miles.

The small boulder exhibited was picked up by one of us with its scored surface resting on the grooved surface of the granite beneath at a point about 100 feet above the level of Hedley Tarn. Hedley Tarn, like Lake Merewether, owes its origin chiefly to a terminal moraine, or rather to what appear to be four closely packed terminal moraines. It is much shallower than Lake Merewether. Its general appearance is shown on the photograph exhibited ; the granite promontory on the left being grooved up to the highest limit shown in the photograph. The nature of the terminal moraine dam is shown. The terminal moraine has four ridges, each doubtless marking a pause in the retreat of the glacier. They are slightly curved, with the convex side directed down the valley. They are formed almost entirely of blocks of slightly foliated granite, from one foot or so up to 10 or 15 feet, or even more, in diameter. There is not now much sandy material between the blocks, which, on the lower side of the moraines, facing the Snowy River, form a rugged belt of huge boulders, difficult to traverse even on foot, the deep hollows between being largely concealed from view by a growth of shrub. This moraine has already been described by one of us (R. Helms, 7, p. 359).

The base of the lowest bank of this moraine material lies at a level of about 5,810 feet, whereas the top of the same bank has an altitude of 5,950 feet, showing a thickness for this lowest and oldest moraine of about 140 feet.

This level of 5,810 feet marks the lowest limit down to which undoubted evidence of glacial action has been found as yet in the Kosciusko region, about 1,500 feet below the summit of Kosciusko, the altitude of which is 7,328 feet.

An examination, however, of Evidence Valley further down to its junction with the Snowy River Valley showed that the rocks were much worn down in a manner very suggestive of glaciation ; and as already mentioned, a few ice-scratched blocks were found there by us down to an altitude of 5,550 feet. The level of the junction of Evidence Valley with the Snowy Valley is about 5,500 feet. At a point a little over one-quarter of a mile up Evidence Valley from its junction with the Snowy is the interesting dyke of phonolite referred to earlier in this paper.

Betts' Camp, Porcupine Ridge, Thompson's Flat, Pretty Point, Boggy Plains, and Valleys of Spencer's Creek and Perisher Creek. —From Betts' Camp to Porcupine Ridge and thence *viâ* Thompson's Flat to Pretty Point, and on to Boggy Plains, there occur at frequent intervals small flats, 200 to 300 yards wide, the floors of which are strewn with small boulders, tightly packed in thin sandy clay, resting on a smooth surface of granite. To the S.E. these flats, are terminated abruptly by slopes towards the Crackenback River, so steep as to be almost precipitous. In a N. by W. direction they slope gradually down to the creeks which flow into the Snowy River.

The smoothing of the granite surface is not apparent at the sides of these flats or on the intervening hills.

On the assumption that these smoothed surfaces are of glacial origin, it would appear that the glaciation must have been of somewhat high antiquity, as the granite on the intervening hills is weathered into large domes, pinnacles and tors. As regards the boulders which are plentifully distributed over the floors of these flats, they were in almost every case such as might have been derived either from the local granites or enclosures in them, or from dykes traversing the granite. A pyroxene amphibolite, in places nearly approaching a hornblende andesite, and passing through decomposition into a chlorite rock, was of frequent occurrence. Clear evidence was obtained that they were derived from dykes intersecting the granite. A great number of these boulders, which varied from a few inches up to $2\frac{1}{2}$ ft. × 1 ft. 8 in. × 1 ft. 3 in. in diameter, were examined by us. In most cases they were far too much weathered to retain the original surface of erosion, and those which did seldom exhibited any grooves or scratches.

In the case, however, of one boulder, found by us *in situ* near Porcupine Ridge, a small cut, apparently of glacial origin, was noticed on its under surface. Marks were also observed on a few blocks of similar rock at Thompson's Flat, but as the latter were not *in situ* and had been moved in the bed of a mountain creek the evidence is not of much value.

Amongst other rocks represented in these detrital deposits, besides the prevailing granite, were felspar porphyries, basalt, and mica schist, in addition to large subangular blocks of quartz; the largest seen, which bears about N. 10° W. from Pretty Point, about half a mile distant, measuring 4 ft. × 4 ft. × 1½ ft.

None of the blocks examined by us from the shallow prospecting shafts near Pretty Point or Boggy Plains exhibited definite glacial cuts or striæ.

With regard to the general evidence of a possible extensive glaciation along the whole Kosciusko Plateau as far down as Boggy Plains (the altitude of which is about 5,220 feet), great caution should, in our opinion, be exercised in interpreting the phenomena. The wide flats strewn with small and large boulders and the smoothed granite rocks bounding such flats are very suggestive of ice-action. If of glacial origin, they may have been formed by ice choking up the Snowy Valley and seeking an escape in an easterly direction into the watershed of the Crackenback River.

One of us (Mr. Helms) has elsewhere advocated this view, and is still of the same opinion, the evidence being given by him in considerable detail in his paper to the Linnean Society of New South Wales (7, pp. 354-356).

Professor Lendenfeld had previously published a general statement as to a former universal glaciation of the Kosciusko Plateau. Two of us (Professor David and Mr. Pittman), while admitting that there is nothing in the evidence inconsistent with the interpretation put upon it by Mr. Helms and Professor

Lendenfeld, would prefer to await more definite evidence before concluding that the whole of the Kosciusko Plateau was formerly buried in ice down to the level of Boggy Plains, or even lower. At the same time the fact may be repeated here that there is positive evidence that the glacier, descending from Mount Twynam *viâ* Evidence Valley and Hedley Tarn towards the Snowy River, came down to a level of about 5,800 feet above the sea; and there is probable evidence of ice-action in this part of the Snowy Valley even as far down as to about 5,500 feet above the sea.

The level of Pretty Point is about 5,990 feet and that of Boggy Plains about 5,220 feet, so that the hypothesis of a wider and older glaciation extending to Boggy Plains does not demand the lowering of the limit which moving ice may have reached very much below that to which we have positive evidence that it did actually descend.

If the Kosciusko Plateau ever underwent such a *mer de glace* glaciation on a small scale, in Cainozoic time, probably the most enduring evidence of it would be in the form of *moraine profonde*, or even a terminal moraine some distance down the Snowy River Valley. A more extended examination of this region may yet lead to the discovery of such evidence.

IV.—Correlation of the Evidences of Glacial Action at Kosciusko with those observed elsewhere.

Before drawing certain provisional deductions which are given in our summary of this paper, it is necessary to review briefly similar evidences of glaciation in Cainozoic time in other parts of the Southern Hemisphere. We have omitted the evidences, described by some authors, from Victoria, as in the opinion of Professor J. W. Gregory the evidences of Post-Tertiary glaciation in such parts of Victoria as he has already examined are doubtful. References, however, to the chief papers referring to this subject are given in the appendix.

(1) *Tasmania.* —Mr. C. Gould, formerly Government Geologist, Mr. C. P. Sprent, formerly Surveyor-General, and Mr. R. M. Johnston, the present Government Statistician, have seen evidences of glaciation in Tasmania in Cainozoic time. The last-named authority has recorded these evidences in his large and detailed work on the Geology of Tasmania, as well as in the Papers and Proceedings of the Royal Society of Tasmania (23, 24).

Mr. T. B. Moore, M. E. J. Dunn, F.G.S., Mr. A. Montgomery, M.A., and Messrs. Graham Officer, B.Sc., Lewis Balfour, B.A., and E. G. Hogg, M.A., have all recorded clear and indisputable evidences of glaciation in Tasmania in late Cainozoic time (26-29).

There is some question as to (*a*) how much of the evidences are Cainozoic and how much Permo-Carboniferous, and (*b*) as to how low down the glaciation extended.

All are agreed that the western highlands of Tasmania in late Tertiary or Post-Tertiary time supported extensive glaciers, which have left memorials of their former presence in the form of lakes, tarns, terminal moraines, striated and grooved rock-surfaces and glacially transported erratics.

Mr. R. M. Johnston has published a map to show the directions in which the ice moved in the Lake St. Clair district (25).

It is also generally agreed that the evidences of this Pleistocene or Pliocene glaciation are clear from levels of 4,000 feet or upwards, down to at least 2,000 feet above the sea (27).

Mr. A. Montgomery, M.A., the late Government Geologist of Tasmania, makes the following statement (26) :—

"I think we must come to the conclusion that the whole of the deep gorges among these western mountains now occupied by the head waters of the Pieman, Henty and King Rivers, have been at no very distant period of time occupied by rivers of ice. The erratic blocks noted by Mr. R. M. Johnston in the Mackintosh Valley bear out this conclusion. . . . If we allow that the deep valleys at the head of the Pieman were once occupied by glaciers, we must admit that *the ice came down to within 500 or 600 feet of the present sea level* [the italics are ours], for these gorges are very deep, or, perhaps, we should rather say, to points which are now that distance above the sea, for of course it is quite possible that there has been elevation or subsidence of the land as a whole since the ice age."

Mr. Montgomery also concludes (*op. cit.* p. 162) that the glaciation could not have been very ancient, basing his inference on the excellent state of preservation of the greenstone erratics and glaciated rock surfaces near East Mount Pelion, among the branches of the River Forth.

Mr. T. B. Moore maintains that the ice during part of this late Cainozoic glaciation came down to within 150 feet of sea level, probably even to sea level on the west coast of Tasmania, near Macquarie Harbour.

He records the occurrence of large ice-worn boulders near Upper Landing on King's River, which flows into Macquarie Harbour, and also at the neighbouring locality of Harvey's Creek, the altitute being only 100 feet above the sea.

He states that between Strahan and Lyell there is a well-marked moraine, quite distinct from and far newer than the Permo-Carboniferous glacial beds, and that a "Giant's Kettle" occurs in connection with this moraine.

Messrs. Officer, Balfour and Hogg, however, consider this moraine to be of Permo-Carboniferous Age (29).

Whether the age of this glaciation at so low a level be Permo-Carboniferous or Post-Miocene, it would appear from Mr. Montgomery's observations that the glaciation near East Mount Pelion at elevations of 2,000-3,000 feet has taken place in Post-Tertiary, possibly in recent geological times.

Messrs. Officer, Balfour and Hogg (*op. cit.* p. 129) state that as the "last of the previous winter's snow had not melted on Olympus by the end of January, it is not necessary to assume a very extensive fall of temperature to account for perpetual snow in these regions."

(2) *New Zealand.*—Dr Haast, Captain F. W. Hutton and Dr. R. von Lendenfeld, and others, have described evidences of what Captain Hutton terms a glacier epoch, as distinct from a glacial epoch in New Zealand (30-33). It is generally agreed by these

authorities that New Zealand during Cainozoic time has passed through an epoch when the glaciers have had a far greater development than at present, for whereas the largest modern glacier of New Zealand, the Tasman Glacier, is 18 miles in length, some of the New Zealand glaciers in Post-Miocene time were upwards of 50 miles long, and in the case of the Wakatipu Glacier, 80 miles long. Captain Hutton has furnished a map showing the relative sizes of the areas formerly glaciated and those at present occupied by glaciers in New Zealand.

The two chief points at present at issue in connection with the glaciation of New Zealand are:—(*a*) As to the date of this glacier epoch; (*b*) as to whether it was due (i) to a general refrigeration of the climate in the Southern Hemisphere, or (ii) to the New Zealand mountains standing several thousand feet higher than they do at present.

Captain Hutton inclines to the last-mentioned view as to the cause of the New Zealand Glacier Epoch. He says (30, p. 211), "I have elsewhere given reasons for concluding that the former great extension of our glaciers was caused by greater elevation of the land during the interval between the Pareora System and the marine beds of the Wanganui System. As these beds are fossiliferous in the North Island only, where there are no traces of former glaciation, it is not possible to get direct proof of this, but in Otago the old Taieri moraine, between Lake Waihola and the sea, which forms low rounded hills between 400 and 500 feet in height, is on the seaward side, covered nearly to the top by marine gravels, which may belong to this sytem or may be younger."

In the Wanganui System, Captain Hutton states (*ibidem*) that from 70 to 90 per cent. of the mollusca and all the brachiopoda are recent. He also states (32, p. 174) that marine fossils in the sandy clays underlying the old Taieri moraine appear to indicate a Miocene Age for these beds, and he suggests that the moraine may be older Pliocene.

He adds that Dr. von Haast found moa bones in morainic deposits belonging to the Wanganui System. He further states

(32, p. 176), "It has been calculated that an elevation of between 3,000 feet and 4,000 feet would be sufficient to expand our glaciers to their former dimensions. That the New Zealand Alps did formerly stand higher than now, we have direct evidence in the deep fiords of South West Otago and Marlborough, which must have been excavated when the land was considerably elevated. The greatest depth recorded in the West Coast Sounds is 1,728 feet in Break Sea Sound; but in many places no bottom was reached with the line used, and we may safely assume that when the valleys were scooped out they stood more than 2,000 feet higher than they do now, and this agrees fairly well with the quite independent estimate that an elevation of 3,000 to 4,000 feet would be sufficient to reproduce all the phenomena." Captain Hutton thus considers the glaciation of New Zealand to have occurred in Pliocene, perhaps older Pliocene time, and to have been due to a former greater elevation of the New Zealand land.

On the other hand, Dr. R. von Lendenfeld is strongly of opinion that the former great extension of the New Zealand glaciers took place in comparatively late geological time, and that it was due to a glacial period synchronous with that which caused the glaciation of Kosciusko (33, p. 808; and 12, p. 52).

In the former paper above referred to, Dr. Lendenfeld states, "The minuteness of the deltas mentioned above (at the heads of the West Coast Sounds, N.Z.) would lead one to suppose that they are of no great age, and comparing them to similar alluvial formations which have been produced in the European Alps in historic time, one must come to the conclusion that the Glacial Period in New Zealand has not been more remote than 2,000 or 3,000 years. This would account also for the extremely fresh appearance of the old moraines and ice scratches." In the latter paper referred to he expresses the opinion that "the state of the preservation of the *roches moutonnées* in the Australian Alps is nothing like so good as in the New Zealand Alps. I am, however, not inclined to ascribe that to a difference in age. I consider it simply as a consequence of the difference in the rocks; there hard metamorphosed slates, here granite." One of us (Mr.

R. Helms) who is familiar with some of the glacial evidences in New Zealand, agrees with Dr. Lendenfeld as to the good state of preservation of the glacial phenomena pointing to a comparatively recent origin, at all events Post-Pliocene. In view of the fact that all the Cainozoic glacial deposits of South America are now considered to be Post-Pliocene, as will presently be explained, the Pliocene, or even older Pliocene Age of the New Zealand glacial evidences may be viewed with great caution, unless it may be admitted that in the Southern Hemisphere, as in the Northern, the glacial epochs of the Ice Age commenced in late Pliocene time, and extended down to at least the close of Pleistocene time.

Kerguelen Island.—H. N. Moseley records evidence of ice action at Betsey Cove and Royal Sound, Kerguelen, close to and even at sea level.

The following statement occurs in the "Challenger" Report (p. 356):—"The interesting feature in relation to these glaciers is that whereas they are to-day confined to the higher valleys of the higher ranges, there are abundant and indisputable evidences that the whole island to and below the sea level was buried under ice at a comparatively recent period. The furrows of glaciers are seen wherever the island has been explored. . . . Every harbour is an ice-cut fiord."

At present, on the south side of the island where the above evidence was obtained, the snow line is between 900 feet and 1,000 feet above sea level.

South America.—Charles Darwin has commented on the greater former extension of the glaciers at Terra del Fuego.*

Also in the same work (pp 242-251) he ably contrasts the climates of Southern South America with those of lands in similar latitudes in the Northern Hemisphere.

The Rev. W. B. Clarke has commented on the analogy between part of Chili and the Australian Alps. He says, "There is a case in South America which very much resembles that of the

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* Naturalist's Voyage Round the World, p. 225. 2nd. edit., 1882.

Muniong (Australian Alps, *authors*), viz., that of Antuco in the southern part of Chili, in lat. 37° 40′, on which snow lies at the height of 7,960 feet, yet even this is far higher in proportion than the snow of Kosciusko " (3, p. 225).

If further observations be omitted (including Baron Nordenskjöld's preliminary report in "Die Geographische Zeitschrift" for 1896) down to within the last few years, we find a summary of his observations in the work noted below, in which he compares the glacial deposits of the Magellan region to the boulder-clay of Europe.*

The same author states in another paper† (p. 408), " Here also (in the neighbourhead of the Gallegos Valley, *authors*) in the neighbourhood of the large depression occupied by the muddy, brackish water of the 'White Lake,' Laguna Blanca, and from there eastwards to the Straits, we find the curious, steep, lofty hills composed of boulder clay, which I observed first in Terra del Fuego, and which are so characteristic of the formerly glaciated territory in this region."

Mr. J. B. Hatcher has also described the Magellan glacial deposits.‡

Referring in a later paper to Mr. Hatcher's observations, Nordenskjöld makes the important statement§ that as regards the age of the Magellan glacial deposits, Hatcher collected some molluscan shells from the Cape Fairweather beds, and Pilsbry has determined these shells to be not older than Pliocene. It is also stated that these shells underlie the oldest glacial deposits of the Magellan Territories.

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* Anales de la Sociedad Cientifica Argentina. Tomo 43-44, 1897, pp. 194-195.

† Geographical Journal. Vol. x. No. 4, October, 1897. A Journey in South-Western Patagonia. By Dr. Otto Nordenskjöld, pp. 401-410.

‡ American Journal of Science. Nov., 1897. Geology of Southern Patagonia. By J. B. Hatcher.

§ American Geologist. Vol. xxi. No. 5, May, 1898. Tertiary and Quarternary Deposits in the Magellan Territories, pp. 300-309. By Otto Nordenskjöld.

Nordenskjöld's conclusions are (*op. cit.* 306-307), that towards the close of the Pliocene Period glaciation set in in the Andean Cordilleras, and enormous quantities of ice collected there giving rise to extensive moraines and a huge development of pampean glacial gravels. Then followed, in his opinion, an inter-glacial period or temporary retreat of the glaciers, with powerful river floods and redistribution of the earlier moraines, " then once more the ice advanced (*op. cit.* p. 307) and extended far down the valleys." He adds (*op. cit.* pp. 307-308), " Many reasons seem to point to the glacial period having lasted down in these regions to, from a geological point of view, quite a recent date, one of the most telling being the great poverty in both the fauna and flora in Terra del Fuego in comparison with Patagonia."

A further account of the glacial deposits of Patagonia is given in a later paper by Hatcher.*

A very important paper bearing on this subject is that by Dr. Francisco P. Moreno in the two numbers of the Geographical Journal.†

Dr. Moreno sums up as follows (*op. cit.* p. 370) :—" In Patagonia an immense ice-sheet extended to the present Atlantic Coast, and further east during the first ice period; while during the second terminal moraines have been generally left as far as 30 miles north and 50 miles south to the east of the present crest of the Cordillera. These ice-sheets, which scooped out the greater part of the longitudinal depressions, and appear to have rapidly retreated to the point where the glaciers now exist, did not succeed in filling with their detritus, in their rapid retirement, the Cordilleran fiords now occupied by deep lakes on the east and by the Pacific channels on the west."

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* Anales de la Sociedad Cientifica Argentina. Tomo xlvii. Primer Semestre de 1899. Buenos Aires, 1899. Estudios Geológicos de la Patagonia. Por J. B. Hatcher.

† Geographical Journal. Vol. xiv. No. 3, Sept., 1899, pp. 241-269, and No. 4, Oct., 1899, pp. 353-378.

With reference to evidences of former greater extension of the Andean glaciers further north, Sir Martin Conway states* (*op. cit.* p. 15), "Evidence is plentiful that in ancient times the glaciers enveloped a large part of these slopes, and reached down many miles further than they do now, depositing the rocks that they carried into the waters of the ancient sea. . . . In the immense pile of débris deep valleys were afterwards cut by the action of water, and into these valleys the glaciers *in a second period of advance* (the italics are ours) protruded their snouts, depositing moraines which can still be traced *in situ* as much as four or even five miles below the present limit of ice. One such glacier cast was carefully examined by me near the foot of Mount Sorata. The terminal moraine now forms the dam of a large lake, 500 feet above the level of whose waters the two lateral moraines can be traced with perfect distinctness."

The evidence, therefore, is overwhelming to show that South America has in Cainozoic time passed through, at all events, two distinct and extensive glaciations, which may range from very late Pliocene into comparatively recent geological time.

V.—Summary.

The evidence obtained in the Australian Alps proves (*a*) that the snowfields of Kosciusko in late Cainozoic time sent small glaciers down the valleys on either side of the Main Dividing Range.

On the western fall, that towards the Murray River, the glaciers at Lake May and Lake Albina descended to levels respectively of about at least as low as 6,600 feet and 6,300 feet. On the eastern fall, towards the Snowy, the glaciers descended to still lower levels. For example, the glacier from Lake Merewether (Blue Lake) in Evidence Valley (Helms) descended to at least as low as 5,800 feet, and probably to 5,500 feet. It would appear, therefore, that the glaciers at Kosciusko

* Geographical Journal. Vol. xiv. No. 1. Explorations in the Bolivian Andes.

descended 500 to 800 feet lower on the eastern fall of the main divide than on the western. There were probably three reasons for this, as already pointed out by one of us (Mr. Helms). (1) The Kosciusko Plateau being constantly exposed to the strong sweep of the W.N.W. anti-trade wind, the chief snow drifts and snow-fields gather to leeward of the main dividing ridge, *i.e.*, on its E.S.E. side, the general trend of the ridge being nearly meridional. (2) The western slopes of the main divide are more heated by the sun's rays than are the eastern, so that snow melts off them quicker than off the eastern slopes. (3) The eastern slopes furnish a more favourable lodging for snow than the western, the eastern slopes being the more gradual of the two.

(*b*) The evidence proves that, apart from the consideration of possible much older and much more extensive glaciation, there have been at least two epochs of glaciation at Kosciusko, of which the traces are clear and fresh, viz. (i) an older epoch which may be termed the Hedley Tarn Epoch; and (ii) a new epoch which may be termed the Lake Merewether Epoch. The double series of terminal moraines on either side of the Main Dividing Range obviously points to this conclusion. The height of these moraine embankments, from 80 up to over 200 feet, and their length, between $\frac{1}{4}$ and $\frac{1}{2}$ mile, prove that the pauses of the ice front at the spots where the moraines became developed must have been of considerable duration.

(*c*) As regards thickness, the evidence shows that the glacier ice must have been about 200 feet and 500 feet thick in the Lake May and Lake Albina valleys on the western fall towards the Murray, while on the eastern fall towards the Snowy it was at least 300 feet thick near the head of the Snowy River, and at least 400 feet thick in Evidence Valley.

(*d*) The longest glacier, that of the Snowy, was perhaps about 3 miles in length.

(*e*) As regards the *age of the glaciation*, it can be estimated at Kosciusko, as far as we could see, only by the amount of subsequent erosion. Such estimates can, of course, be only very approximate.

The data, however, already quoted show that the limit of time may lie somewhere between 3,000 and 10,000 years from the present.

The wonderful freshness of the grooves on some of the "dressed" surfaces and *roches moutonnées*, west of Lake Merewether, Kosciusko, in positions where the rocks could not have been sheltered by moraine material proves that the glaciation was in a geological sense comparatively recent.

We would here like to emphasise the opinion that it is out of the question to refer either the Hedley Tarn glacial epoch or the Lake Merewether glacial epoch of Kosciusko to Tertiary time. We are strongly of opinion that these epochs belong to the Post-Tertiary. If, however, later examination proves that there was a much earlier and far more extensive glaciation which affected the whole of the Kosciusko Plateau and extended even as far down as Lake Coolamatong near Berridale (Plate vi.), (about 2,500 ft. above the sea) as one of us (Mr. Helms) thinks, it is quite possible that this older glaciation may belong to Tertiary time.

(*f*) As regards the position of the snow line at Kosciusko at the maximum extension of ice during the earlier of the two glacial epochs (of the existence of which we have definite proof), the present mean temperature of Kosciusko may be taken to be about 35° Fahr. At the sea-level, in the latitude of Kosciusko, the mean temperature would be about 59° Fahr. At a rate of fall of 1° Fahr. for 345 feet a mean temperature of 32° should be reached at Kosciusko at about 8,200 feet. (The present level at the summit of Kosciusko is 7,328 feet). During therefore the earlier glaciation of the two comparatively recent glacial epochs at Kosciusko, as the ice came down to about 5,500 feet above the sea, the snow line may have been lowered from 8,200 feet to about 5,500 feet (though of course the glaciers of Kosciusko, like many modern glaciers, may have descended below the snow line). This would have meant a lowering of the snow line to the extent of from 2,200 to about 2,700 feet, equal to a lowering of the mean temperature by about $6\frac{1}{2}$° up to about 8°, and if Lake Coolamatong near Berridale be glacial, the level being about 2,500 feet above the sea, the lowering of the temperature may have been somewhere about 15° to 16° Fahr. This estimate assumes, of course, that since the glaciation the Kosciusko Plateau altitude has not been appreciably affected by crustal movements or by denudation, and that in other respects meteorological conditions in the past have resembled those of the present

(*g*) As regards collateral evidences, in the Southern Hemisphere, of glaciation in late Cainozoic time, Tasmania shows a lowering of the snow line by about at least 2,500 to 3,000 feet, possibly as much as 4,000 feet, if Mr. T. B. Moore's views as to the age of the moraines near sea-level in the neighbourhood of Macquarie Harbour on West Coast of Tasmania are correct. This might mean a lowering of the temperture by about 12° Fahr., subject, of course, to assumptions similar to those just made in the case of Kosciusko. In New Zealand the evidence adduced shows that the glaciers in the South Island on the east side of the Alps came down to probably at least 3,000 to 4,000 feet below their present terminations. Captain Hutton, however, argues that this did not necessarily imply a general lowering of the snow line to the same amount. He thinks that the extension of the glaciers in New Zealand in late Cainozoic time was due, as already stated, to the South Island at that time standing 3,000 to 4,000 feet higher than it does at present. He states emphatically, "The biological evidence is therefore to the effect that the ocean round New Zealand has not been much colder than at present ever since the Miocene Period."* Even biological evidence, however, is not always reliable, as Charles Darwin has pointed out.†

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* Rept. Aust. Assoc. Adv. Sci. Vol. v. 1893, p. 240.

† Naturalist's Voyage Round the World, 1882, p. 243. "A large Voluta is abundant in Southern Terra del Fuego and the Falkland Islands. At Bahia Blanca, in lat. 39° S., the most abundant shells were three species of Oliva (one of large size), one or two Volutas, and a Terebra. Now these are among the best characterised tropical forms. It is doubtful whether even one small species of Oliva exists on the southern shores of Europe, and there are no species of the two other genera. If a geologist were to find in lat. 39° on the coast of Portugal a bed containing numerous shells belonging to three species of Oliva, to a Voluta and a Terebra, he would probably assert that the climate at the period of their existence must have been tropical; but judging from South America such an inference might be erroneous."

It would be presumption on our part to express any opinion on this important point. At the same time, in view of the evidence lately obtained in South America, Tasmania and Kosciusko, it might be as well for the New Zealand geologists to enquire further into the interpretation of their evidence. In Kerguelen Island the snow line would appear to have been formerly (in late Cainozoic time) at least 1,000 feet lower than at present, and in South America several thousand feet lower, though, as far as we can learn, the exact amount has not yet been calculated. In South America, moreover, there is evidence of at least two distinct epochs of glaciation.

(*h*) In our opinion, even if the case of New Zealand, as being still *sub judice*, be omitted from consideration, the general evidence points to a universal glacial period, of at least two phases or epochs, in the Southern Hemisphere. If these provisional deductions are correct, at least two very important questions suggest themselves for further investigation:—

(1.) Did the glaciation of the Southern Hemisphere lead to definite biological migrations similar to those due to the "Great Ice Age" in the Northern Hemisphere?

(2) If the glaciation of the Southern Hemisphere was synchronous with that of the Northern Hemisphere, as now seems probable, was it due to some great cosmic atmospheric cause, as suggested long ago by Tyndall, such as the variation of the amount of CO_2 in the earth's atmosphere, as lately investigated by Dr. Arrhenius and Mr. Högbom,* and advocated by Professor Chamberlin? †

* Phil. Mag., April, 1896, pp. 237-276, and Journ. Geology, Vol. vii. Nos. 6, 7 and 8, 1899.

† In connection with this one of us (Prof. David) would suggest that the greater cold at present of the Southern Hemisphere as compared with the Northern may be due to the former having a thinner blanket of air than the latter. The data on this point at present are insufficient, of course, for generalisation, but as far as they go are in favour of the view that atmospheric pressure, and consequently atmospheric thickness, is less in the Southern than in the Northern Hemisphere.

(3) If the glaciation of the Southern Hemisphere was synchronous with that of the Northern, and was accompanied by an appreciable increase in size of the Antarctic ice-sheet, to what extent was sea level lowered in various latitudes through the withdrawal of so much sea water to form the ice-sheets in each hemisphere?

In submitting to this Society the above notes, we are sensible that the information contributed is indeed small in proportion to the wideness and grandeur of the subject.

A vast unknown remains behind full of promise for future investigators. Our observations have, however, we think, finally set at rest a vexed question, and have entirely confirmed the view that the "Roof of Australia," at no very distant date, certainly supported glaciers, and, perhaps, at some earlier date may have even been buried under a "mer de glace."

We desire to express our special obligation to Mr. W. S. Dun for much valuable information as to current literature relating to the glaciation of the Southern Hemisphere in late Cainozoic time. We are also much indebted to Mr. F. B. Guthrie, F.C.S., who accompanied us to Kosciusko, for his constant help and kindly criticism. We also gratefully acknowledge the courteous hospitality of Messrs. P. S. Whelan and P. A. Harding, the officers in charge at Mr. Clement Wragge's Meteorological Observatory at Kosciusko, and the kind help of Mr. G. W. Card, Assoc. R.S.M., F.G.S., in the determination of the rock specimens from Kosciusko, as well as to Professor J. W. Gregory, of Melbourne, for his note on Dr. Arrhenius' theory.

Postcript (added June 10th, 1901)—Since the above paper was read, Professor J. W. Gregory, of Melbourne, has written to one of us with reference to Dr. Arrhenius' theory as follows:—

"Thinking again over the CO_2 theory of glaciation, I am less inclined to it for the following reasons:—

"(1) Glaciations are not synchronous. There is no evidence of glaciation in Europe or America at the time of the Palæozoic glaciation in Australia and South Africa (Ramsay's Permian breccia is now otherwise explained). Similarly, though there are remains of Pleistocene glaciation in the lands between 40-50° S., there does not appear to have been any such extreme glaciation as affected corresponding latitudes in Europe and America.

"(2) Even adjacent glacial areas are not subject to their maximum glaciation at the same time. Thus N. America has had four main glacial centres, the Cordilleran (Rocky Mountains), the Kewatin (Minnesota, &c.), Labrador, and Greenland. The glaciations at these centres succeeded one another from west to east. The Labradorian glaciation was the last on the mainland; it was succeeded by the growth of the Greenland glaciers, which have perhaps not yet reached their maximum. The evidence certainly points to the fact that the Greenland glaciers have now a greater extension than they have ever had before.

"(3) Schloessing's theory seems probable. According to this the sea is a great reservoir of CO_2 held in the form of bicarbonates; any diminution in the CO_2 content in the atmosphere at once leads to dissociation of the bicarbonates in the sea, which thus automatically regulates the amount of CO_2 in the air. Any such variation as Arrhenius' theory requires would, therefore, be impossible.

"In face of the evidence of the variation of CO_2 in latitude (summarised by Letts & Blake), and of Dittmar's opinion that Schloessing is right, we cannot safely assume an adequate CO_2 variation in the atmosphere. Dittmar's opinion was founded on his own experiment, showing that the dissociation of bicarbonates in sea water corresponds to the CO_2 tension in the air."

With reference to argument (1) mentioned above by Professor Gregory, we think should be considered the very important discovery by Mr. Walter Howchin, F.G.S., of immense glacial boulder beds in the Lower Cambrian of S. Australia, extending over at least 400 miles of latitude, as recorded in his paper just read to the Royal Society of South Australia. This glaciation may perhaps be homotaxial (though not necessarily synchronous) with that of the Cambrian (?) glacial beds of Scandinavia.

EXPLANATION OF PLATES III.-X.

Plate iii.

Map showing some of the chief evidences of glacial action, Mount Kosciusko, New South Wales.

Plate iv.

Fig. 1.—Map showing the glacial moraine and striated pavement near the head of the Snowy River, about $1\frac{1}{2}$ miles N. by E. from Mount Kosciusko.

Fig. 2.—Longitudinal Section on line AB.

Fig. 3.—Section on CD across lower end of moraine showing amount of erosion by creek since close of latest glaciation, viz., about 9 feet in depth of moraine and an additional 10 feet of slate rock (phyllite).

Plate v.

Fig. 1.—Longitudinal Section showing terminal moraines and former thickness of glacier ice in Cootapatamba Lake Valley, Mount Kosciusko.

Fig. 2.—Section across Lake Albina Valley showing probable former thickness of glacier ice.

Fig. 3.—Longitudinal Section from Mount Twynam to Snowy River showing terminal moraines and former thickness of glacier ice in the Blue Lake Valley (Evidence Valley).

Plate vi.

Geological Section from Cooma to Mount Kosciusko.

Plate vii.

Roche Moutonnée of gneissic granite showing glacial grooves, the "lee-side" lying to the left. The white vein is aplitic granite parallel to the gneissic folia. About 200 yards S.W. of Lake Merewether, Kosciusko, and looking S.W. Photo by E. F. Pittman.

Plate viii.

Striated boulder of quartzite found on surface of glaciated granite north of Lake Merewether, Kosciusko. Photo by E. F. Pittman.

Plate ix.

Grooved and striated boulder of quartzite found resting on glaciated surface of gneissic granite, about 300 yards S.W. of Lake Merewether, Kosciusko.

Plate x.

Fig. 1.—Grooved pavement of gneissic granite in foreground, with Lake Albina, Kosciusko, in middle distance, with large granite erratics stranded on the slope of the slate hill at the back, toward the left and middle of the picture. Photo by E. F. Pittman.

Fig. 2.—Relic of lateral moraine, near Townsend's Pass, Kosciusko, with Snowy Valley in distance, looking easterly. Photo by T. W. E. David.

APPENDIX OF CHIEF WORKS CONSULTED.

i.—Cainozoic Glaciation in Southern Hemisphere.

A. *Australia in general.*

1.—Tenison-Woods (Rev. J. E.)—On the Glacial Period in Australia. *Trans. & Proc. R. Soc. Victoria*, viii., 1867, pp. 43-47.

2.———— Physical Structure and Geology of Australia. *Proc. Linn. Soc. N.S. Wales*, vii., 1882, pp. 371-389.

B. *New South Wales.*

3.—Clarke (Rev. W. B.)—Researches in the Southern Gold Fields of New South Wales. Sydney, 1860. See especially pp. 225, 226, 228, and 230.

4.—Curran (Rev. J. M.)—Exhibit of photographs and rock-specimens illustrative of the physiography and geology of the Mt. Kosciusko Plateau, especially in relation to the so-called evidences of Glaciation; with Remarks thereon. *Proc. Linn. Soc. N.S. Wales*, xxi. Pt. 4, p. 819, Nov. 1896 [May, 1897].

5.————On the Evidence (so-called) of Glacier Action on Mount Kosciusko Plateau. *Op. cit.* xxii. Pt. 4, pp. 796-809, pls. xxxvii.-xxxix., Nov. 1897 [June, 1898].

6.—Helms (R.) – Exhibit of Glacier-polished Slab from Moraine at base of Mt. Twynan, Snowy Mts., Australian Alps. *Proc. Linn Soc. N.S. Wales*, (2), viii. Pt. 2, p. 328, September, 1893 [March, 1894].

7.————On the recently observed Evidences of an extensive Glacier Action at Mount Kosciusko Plateau. *Op. cit.* (2), viii., Pt. 3, pp. 349-364, pl. xviii., October, 1893 [April, 1894].

8.———— The Australian Alps, or Snowy Mountains. *Journ. R. Geog. Soc. Aust, Sydney*, iv. No. 4, pp. 75-96, Oct.-Dec., 1896. See especially pp. 78 and 83.

9.—Jaquet (J. B.)—Geological Notes upon a Trip to Mount Kosciusko, New South Wales. *Records Geol. Surv. N.S. Wales*, v., Pt. 3, 1897, pp. 113-117.

10.—Kitson (A. E.) and Thorn (W.)—Contributions to the Geology of Mount Kosciusko and the Indi-Monaro Track. *Report Aust. Assoc. Adv. Sc.*, vii., Sydney, 1898 [1899], pp. 367-370.

11.—Lendenfeld (R. von)—Report on the Results of his recent Examination of the Central Part of the Australian Alps, pp. 1-16, pls. i.-vi. Govt. Printer, Sydney, Jan. 21st, 1885.

12.————The Glacial Period in Australia. *Proc. Linn. Soc. N.S. Wales*, x. Pt. 1, pp. 44-53, pls. vii.-viii., Jan., 1885 [June].

13.———— ———— *Petermann's Mittheilungen*, 1887, *Ergänzungsheft*, No. 87.

C. *Victoria.*

14.—Griffiths (G. S.)—On the Evidences of a Glacial Epoch in Victoria during Post-Miocene Times. *Trans. & Proc. R. Soc. Victoria*, xxi., 1884 [1885], pp. 1-28.

15.—Howitt (A. W.)—The Physical Geography and Geology of North Gippsland, Victoria. *Q.J.G.S.*, xxxv., 1879, pp. 1-41. See especially p. 35.

16.———— Notes on Lake Karng. *Reports and Statistics of the Mining Department, Victoria, for Quarter ended 30th September, 1891*, pp. 26-30, with plates.

17.—Kitson (A. E.)—Geological Notes on the Gehi and Indi Rivers and Monaro Gap, Mount Kosciusko, N.S.W. *Proc. R. Soc. Victoria*, n.s. ix., 1897, pp. 22-28.

18.—Stirling (J.)—The Physical Features of the Australian Alps. *Trans. & Proc. R. Soc. Victoria*, xviii., 1881, [1882], pp. 98-110, with two plates.

19.—Stirling (J.)—Notes on the Meteorology of the Australian Alps. *Op. cit.* xxi., 1884, [1885], pp. 144-145.

20.————Notes on Evidences of Glaciation in the Australian Alps. *Op. cit.*, xxii., 1885 [1886], pp. 20-34.

21.————Physiography of the Tambo Valley. *Trans. Geol. Soc. Australasia*, Vol. i. Pt. 2, Melbourne, 1887. See especially p. 49.

D. *Tasmania.*

22.—Dunn (E. J.)—Glaciation of the Western Highlands of Tasmania. *Proc. R. Soc. Victoria*, n.s. vi·, 1893, [1894], pl. viii. See especially pp. 134-135, 137-138.

23.—Johnston (R. M.)—Geology of Tasmania. By authority· Hobart, 1888. See especially pp. 254-257, and 296.

24.————The Glacier Epoch of Australasia. *Papers & Proc. R. Soc. Tasmania for 1893*, pp. 73-134, [June, 1894].

25.————Notes on the Geology of Lake St. Clair and its immediate Neighbourhood, together with Observations regarding the probable Origin of our numerous Tasmanian Lakes and Tarns. *Op. cit. for 1893*, pp. 135-146, [1894].

26.—Montgomery (A.)—Glacial Action in Tasmania. *Op. cit. for 1893*, [1894], pp. 159-169. See especially pp. 162 and 164.

27.—Moore (T. B.)—Discovery of Glaciation in the Vicinity of Mount Tyndall, in Tasmania, with Supplementary Notes. *Op. cit. for 1893*, pp. 147-149, [1894].

28.————Notes on further Proofs of Glaciation at lower Levels. *Op. cit. for 1894-95*, [August, 1896], pp. 73-77.

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NOTES AND EXHIBITS.

Mr. Maiden exhibited specimens of the Acacia described in his paper.

Messrs. David, Helms and Pittman exhibited a series of lantern views, photographs, coloured diagrams, glaciated boulders, rock specimens, and rock-sections under microscopes, illustrating in detail the geology of the Kosciusko plateau.